Low Temperature Mobility and Mechanisms

By

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Overview

- Introduction
- Example mechanisms: rover mobility
- Example mechanisms: sampling systems
- Tribological options & materials choices
- Summary & Conclusions

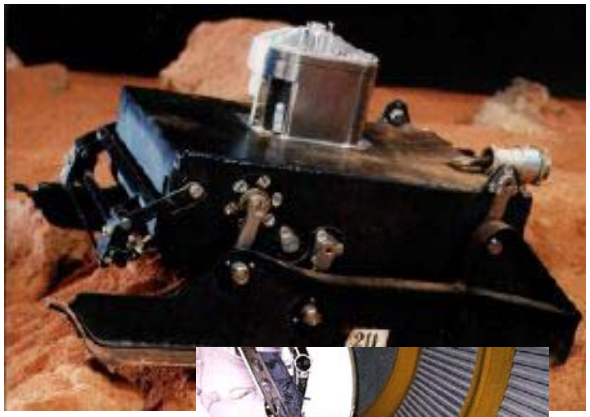
Introduction

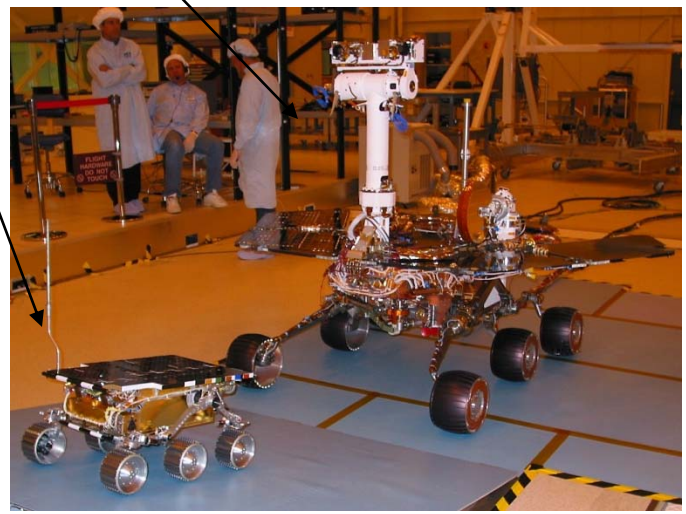
- Low temperature mechanisms:
  - No universally accepted definition, but: *environmental* temperature < Earth ambient (which can be as low as -50 C)
  - Typical cases:
    - Mars surface missions (operation down to -90 C environmental temperature typically required)
    - Outer planet moons surface missions (operation down to -200 C environmental temperature typically required)
    - Special, cryogenic applications: mechanisms in front ends of cryogenically cooled space telescopes (operation down to -250 C environmental temperature typically required)
    - Mechanisms in free space at large solar distances: e.g. pointing mechanisms
- Issues: proper choice of tribological elements & treatments; temperature gradients (temporal & spatial); use of local heaters to condition elements

Example low temperature mechanisms – Mars surface mobility

Mars rovers – past and present

- Flown:
  - PROP-M (1971/73)
  - Mars Pathfinder/Sojourner (1997)
  - MER Spirit & Opportunity (2004-present)
- In development:
  - MSL (2009 launch)
  - ExoMars (2013 launch)
- Technology studies (over the years/decades):
  - Various: Marsokhod,…





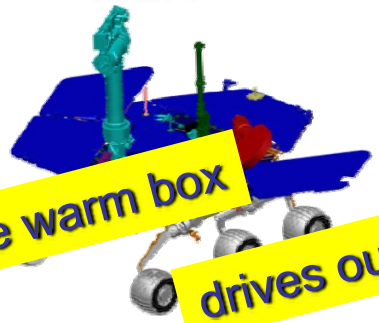
Mars rovers – where are the mechanisms?

- JPL rocker-bogie vehicles (Sojourner, MER, MSL) & ExoMars: thermally exposed to ambient conditions (e.g. in wheel hubs) but have heaters
- Concept studies: in rover warm compartment, with gears transmitting torque through suspension

Sojourner

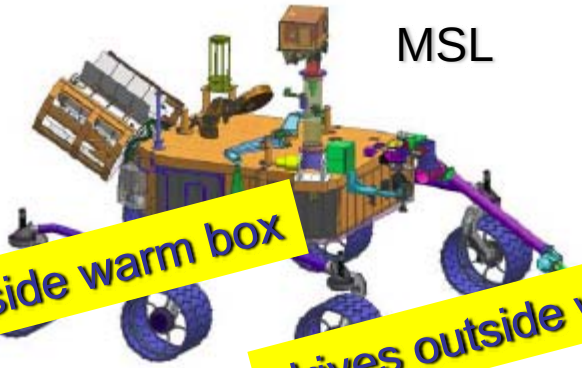
drives outside warm box

MER



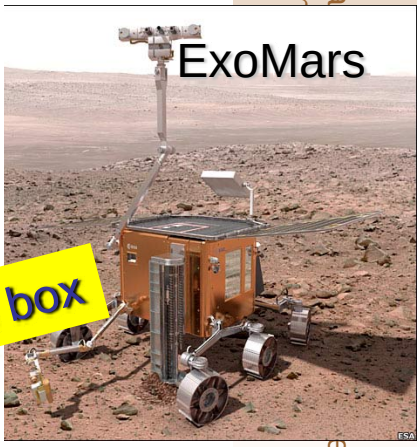
drives outside warm box

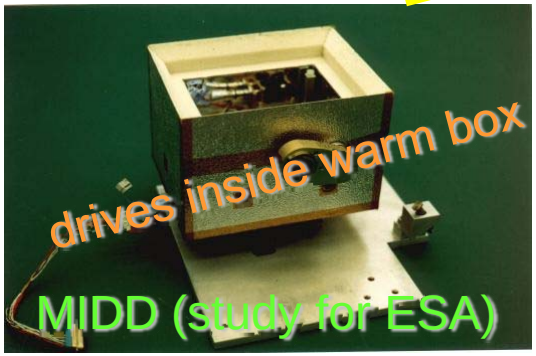
MSL



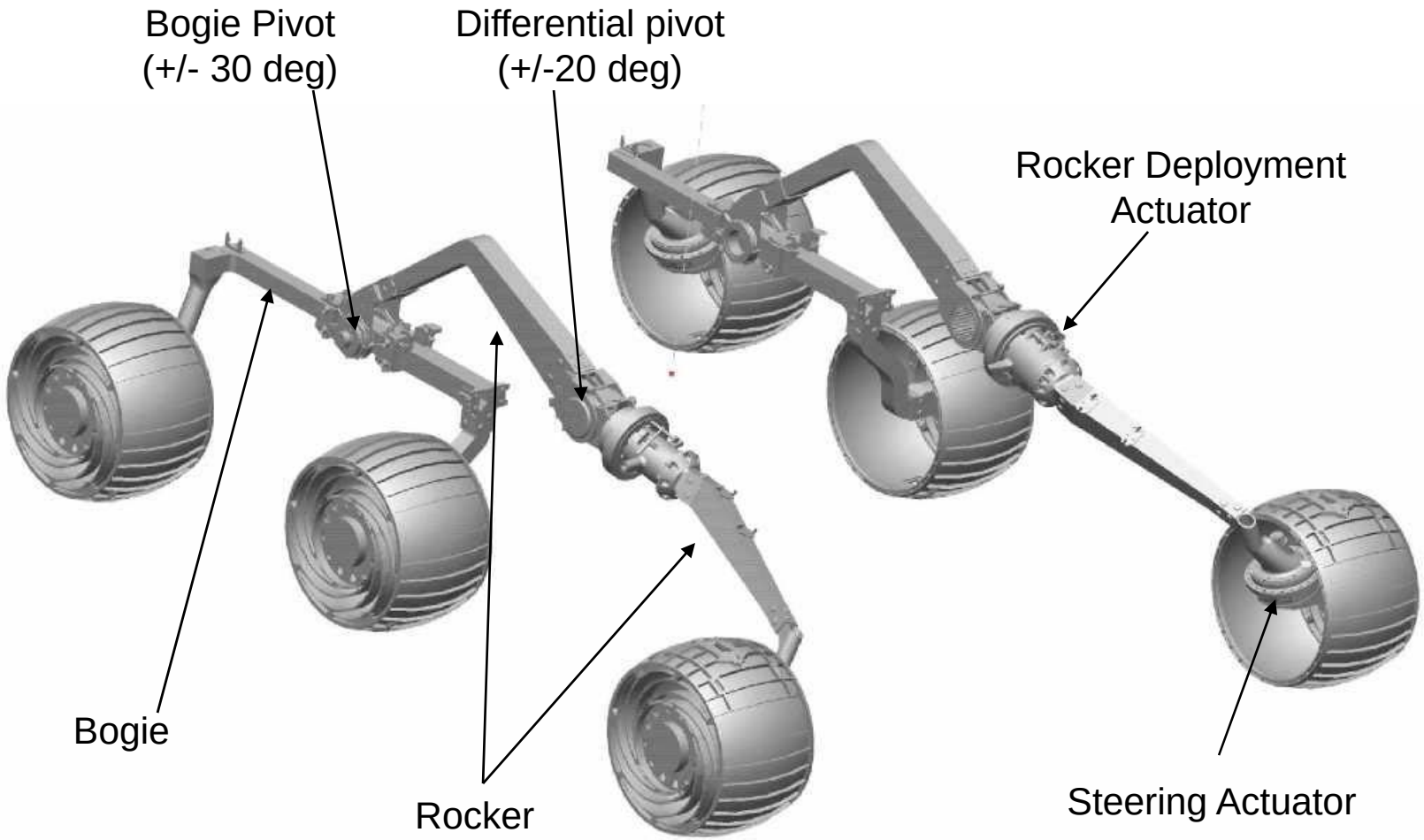
drives outside warm box

ExoMars





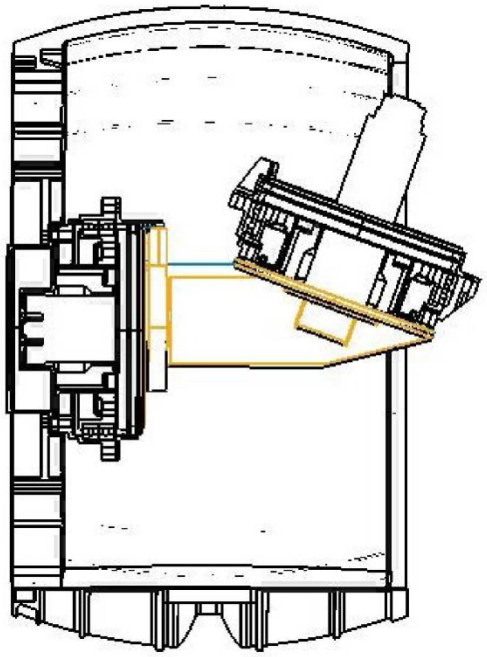
MER mobility mechanisms

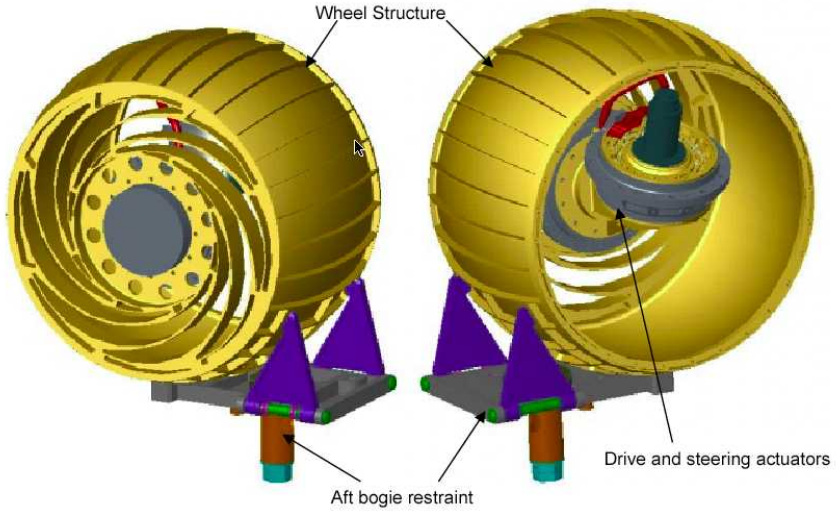


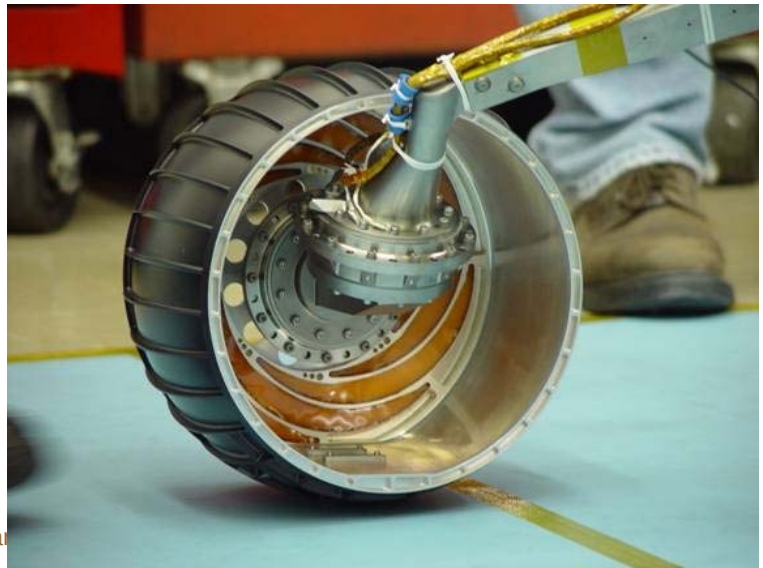
MER mobility mechanisms

MER mobility mechanisms

- Wheel with internal traction and steering mechanisms

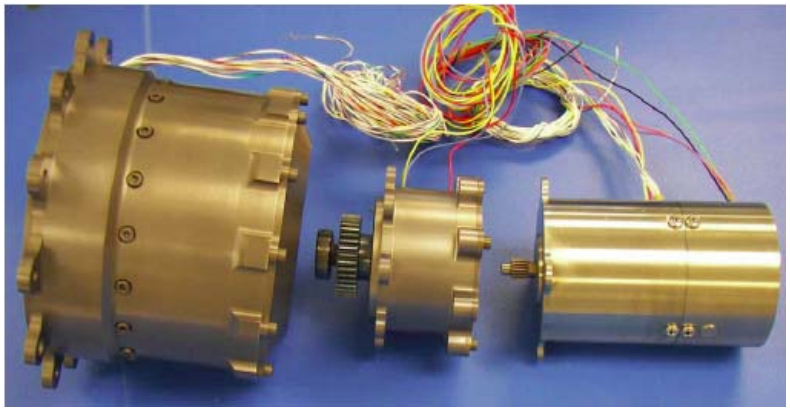


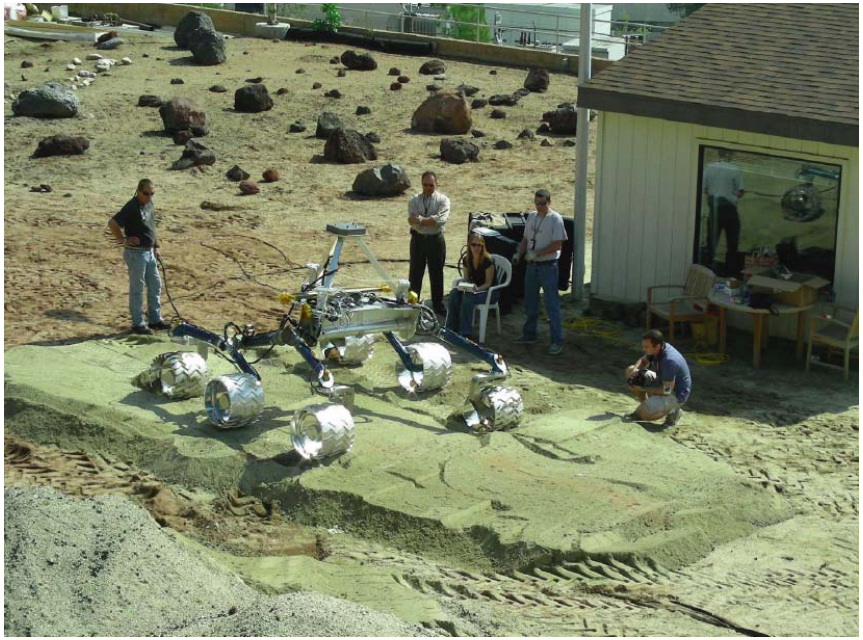




MSL

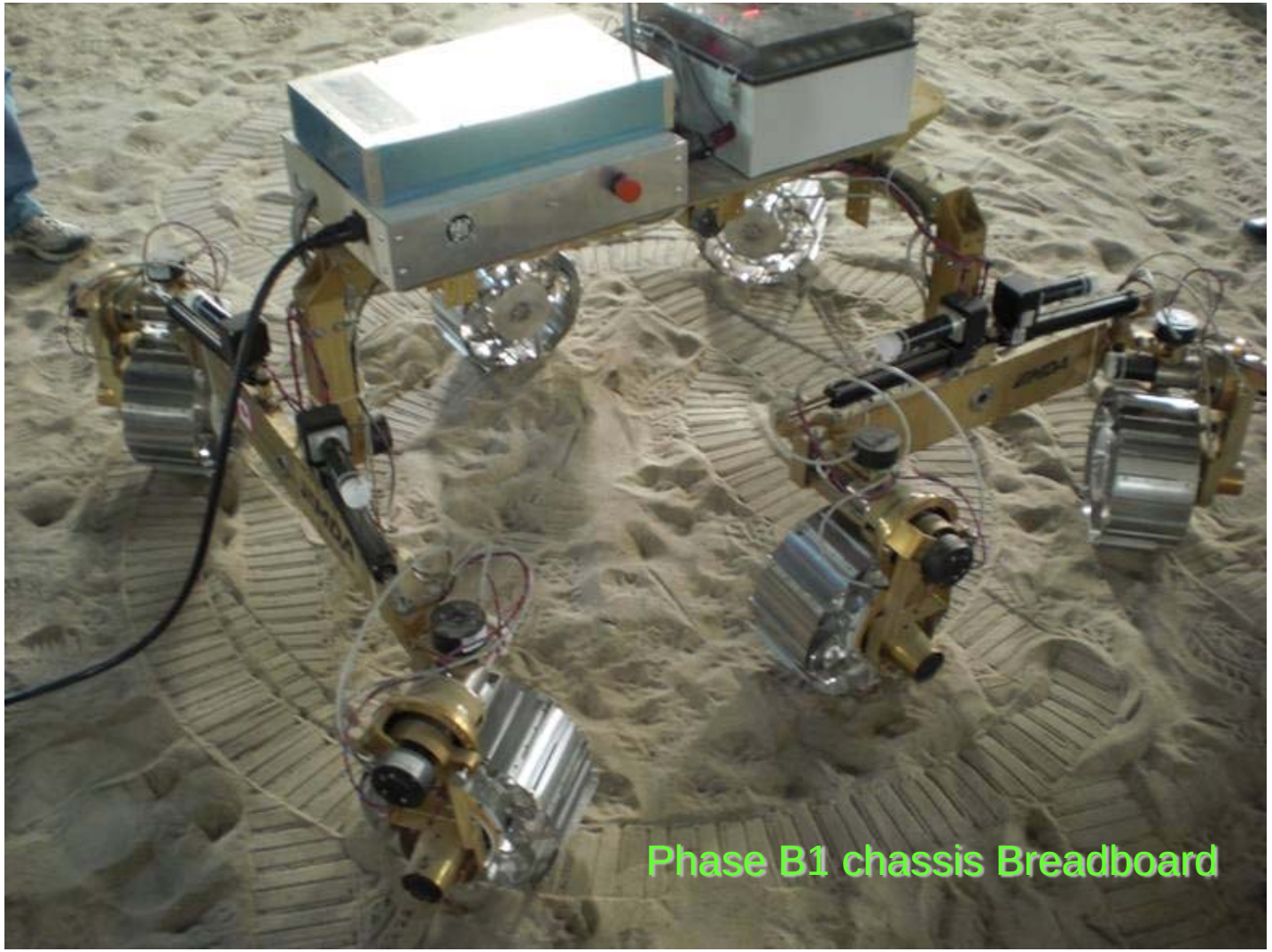
Wheel traction drive elements



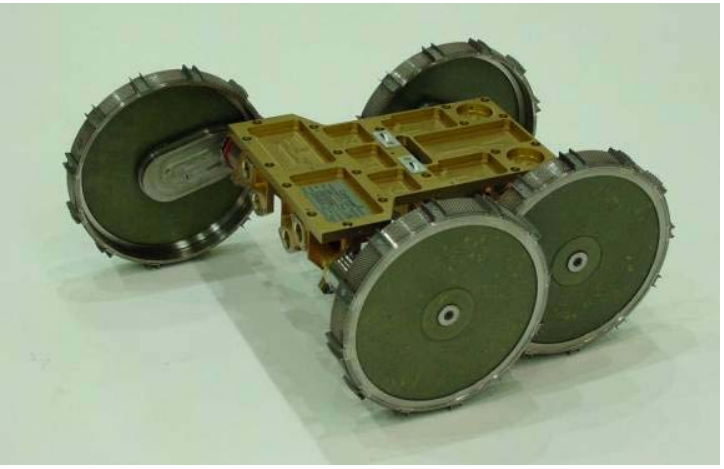


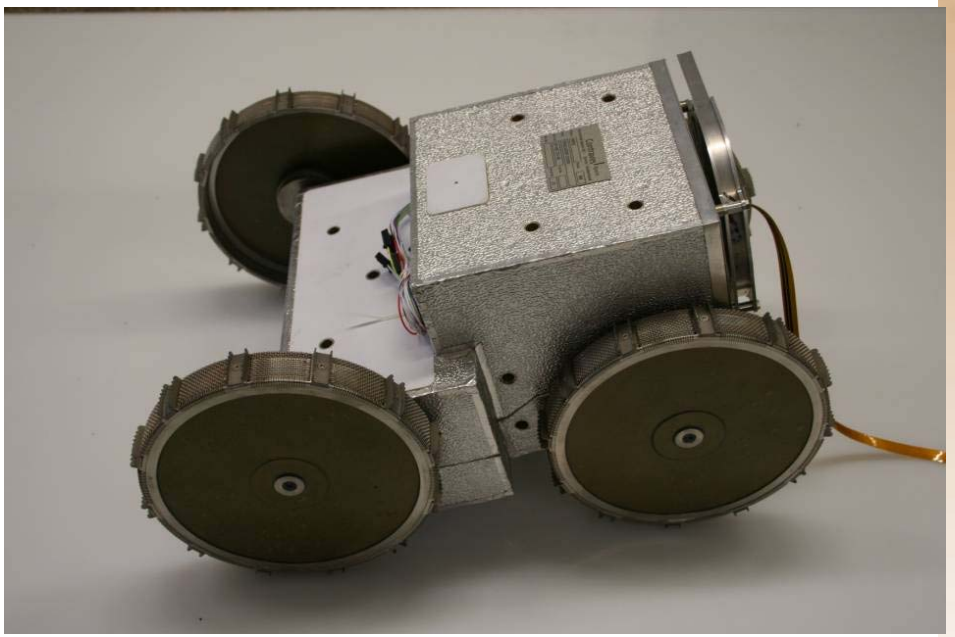
‚Scarecrow' outdoor test

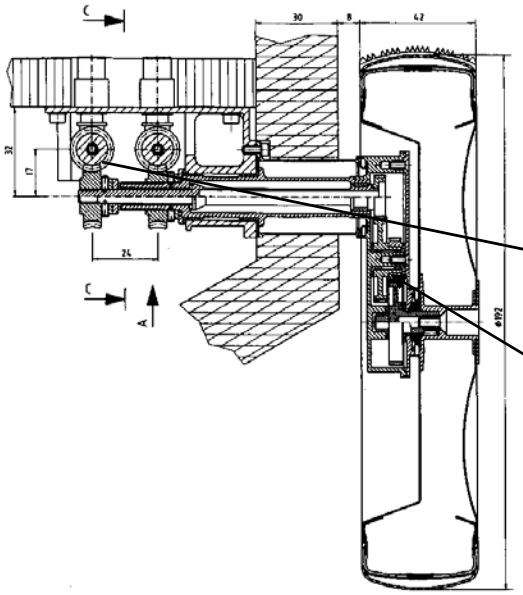
ExoMars



Concept study: MIDD 4 kg, 4-wheeled rover for Mars

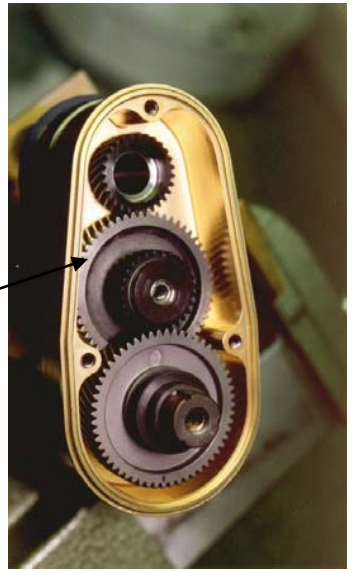






- actuators inside warm compartment!

- gear train going to wheel

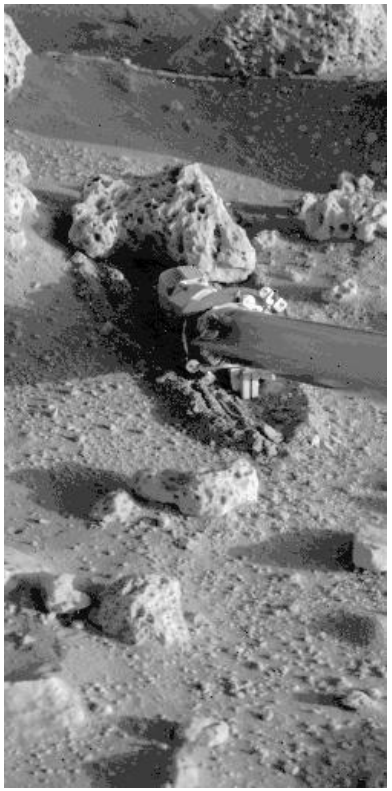


Example low temperature mechanisms – Mars drills & other tools

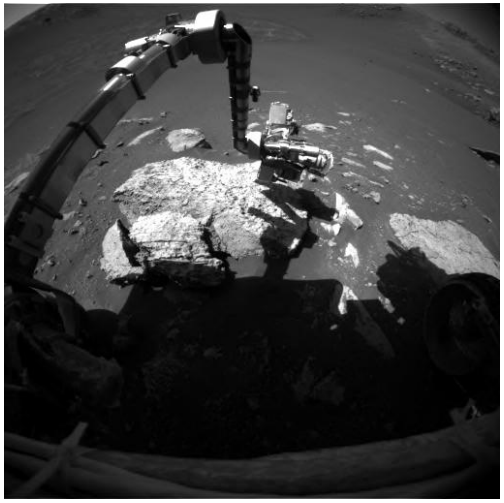
- Flown:
  - Viking lander telescopic sampling arm/scoop (1976)
  - MPL & PHX jointed sampling arm/scoop (1999 & 2007)
  - MER IDD arm (2003)
  - MER RAT (2003)
  - Beagle arm (2003)
  - Beagle sampling mole (2003)
- In development:
  - MSL arm/scoop (2009 launch)
  - MSL rock sampler (2009 launch)
  - ExoMars rover drill (2013 launch)
- Other drills:
  - Rosetta lander sampling drill to a comet (2004 launch, 2014 operstions)
- Technology studies:
  - Various

Example low temperature mechanisms – Mars drills & other tools

- Arms:

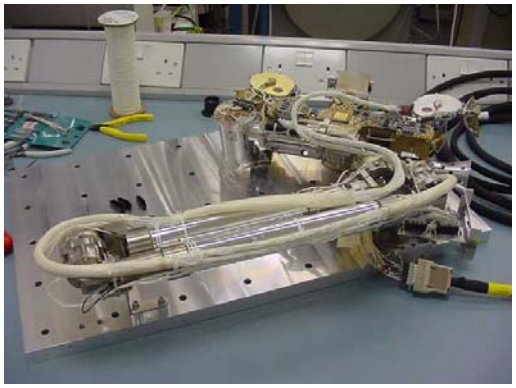


VL arm w/ scoop



MER IDD w/ contact instruments

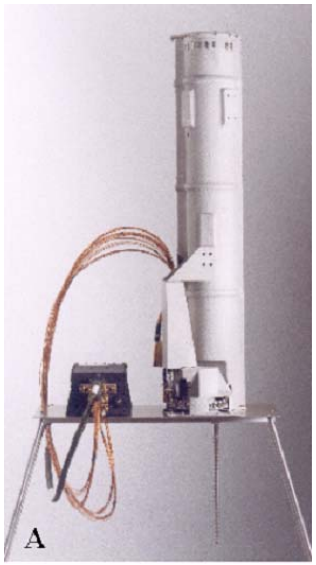
PHX arm w/ scoop



Beagle arm w/ contact instruments & samplers

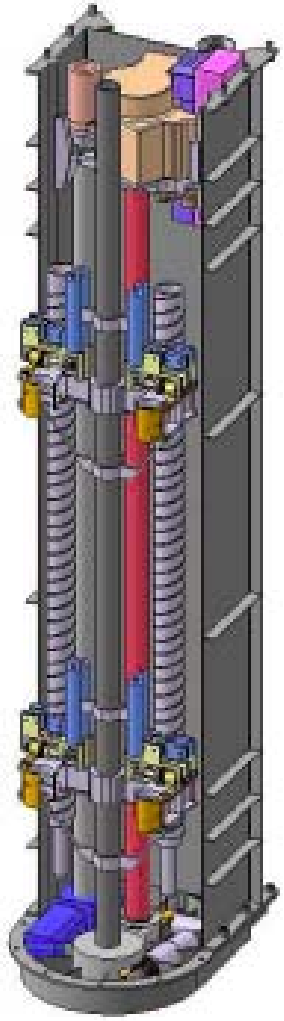
Example low temperature mechanisms – Mars drills & other tools

- Drills & other subsurface samplers:



Rosetta lander drill

Beagle sampling mole



ExoMars sampling drill

Tribology at low temperature

- Moving parts: need to control friction and contain wear
- Method: use lubrication
- Two basic choices for space:
  - Solid lubricants: coatings
  - Liquid lubricants: greases, oils
- Low temperature missions (definition: see introduction & previous speaker): greases & oils may become solid

  -> general limit for space greases: ~ -75 C lubricant temperature (pour point) -> foresee local heaters or choose solid lubricant instead

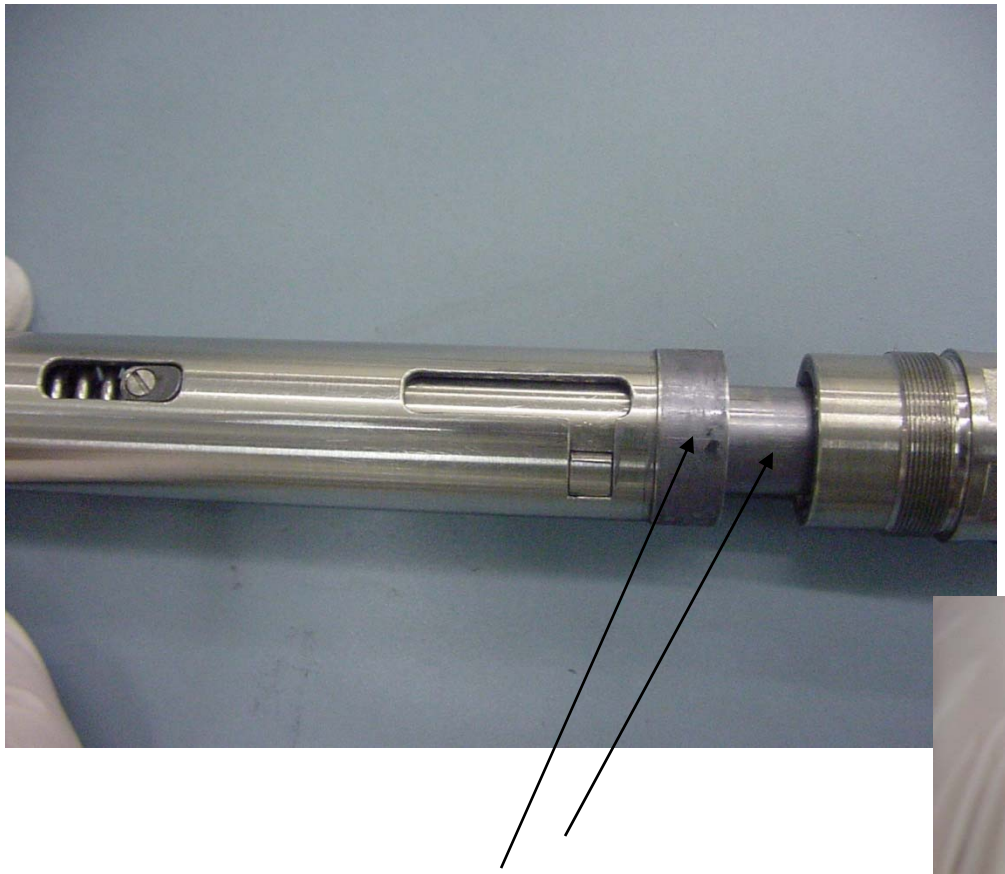
Pro‘s & con‘s of lubricant options

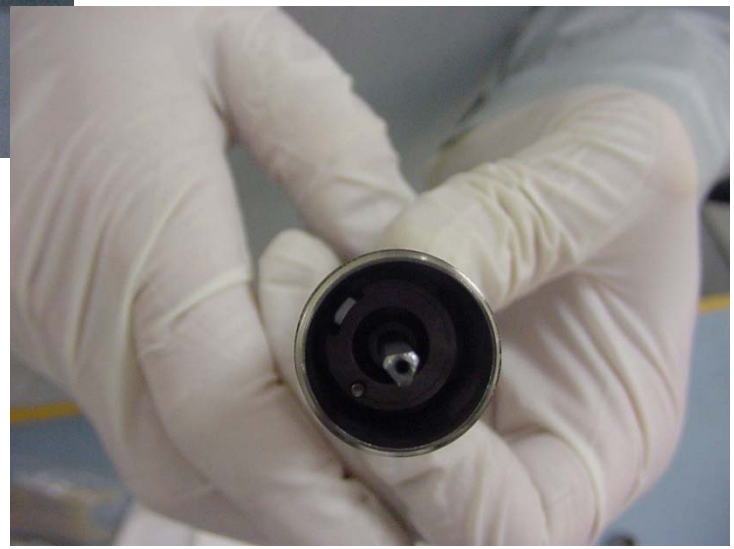
- Solid lubrication (example: MoS_2 coating by sputtering or bonding):
  - Good for very low (and also high) temperature
  - No outgassing/condensation issues
  - Can do accelerated mechanism life testing (saves time & cost of test program)
  - Requires careful application & handling (degrades in presence of humidity)
- Liquid lubrication (example: PFPE greases):
  - Robust method, easy to apply (however: care in parts materials selection), insensitive to humidity (ground handling & testing)
  - Temperature limits (previous slide)
  - Cannot do accelerated testing (would change flow regime)
  - Good for use in atmospheres (Mars, but not Titan as too cold unless have heaters…)

Mars surface mechanisms: how has it been done?

- Sojourner & MER mobility mechanisms:
  - PFPE grease as lubricant
  - Local electrical heaters
- MER deployment mechanisms (short required life):
  - Dry lubrication
- Beagle mechanisms (deployment functions, arm, mole sampler, rock corer):
  - PFPE grease as lubricant
  - Some elements: MoS_2 bonded coating
- MSL mobility mechanisms:
  - Planned to use MoS_2 coating on Ti gears (for lower allowed operating temperature at high latitude landing sites) -> ran into problems -> final solution: ?

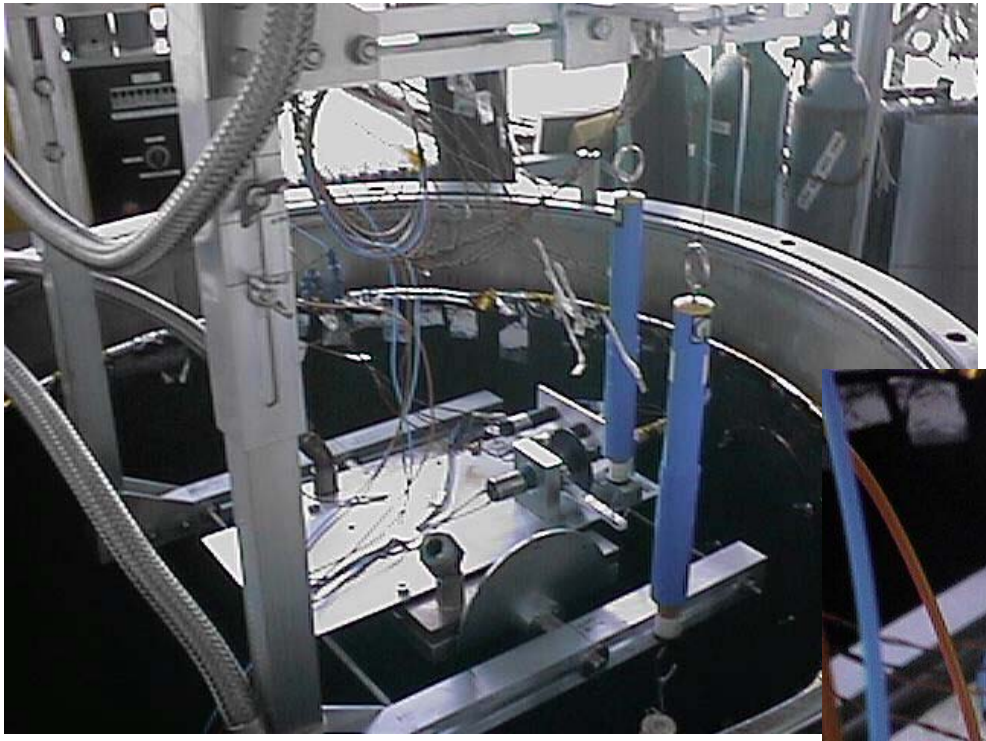
Mars surface mechanisms: how has it been done?

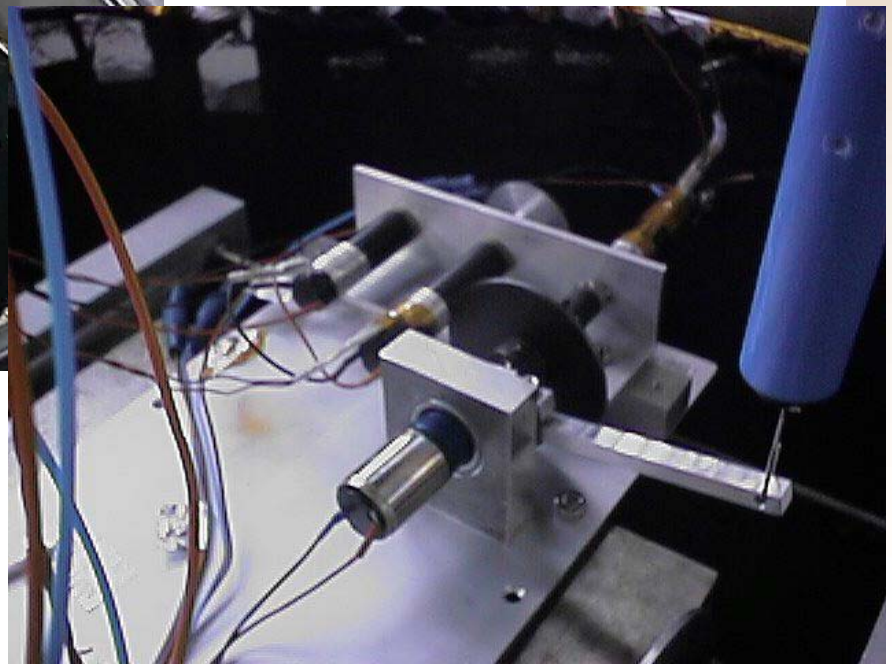




Beagle mole internal hammering mechanism: bonded coating of MoS_2 with Formaldehyde on slider bearings

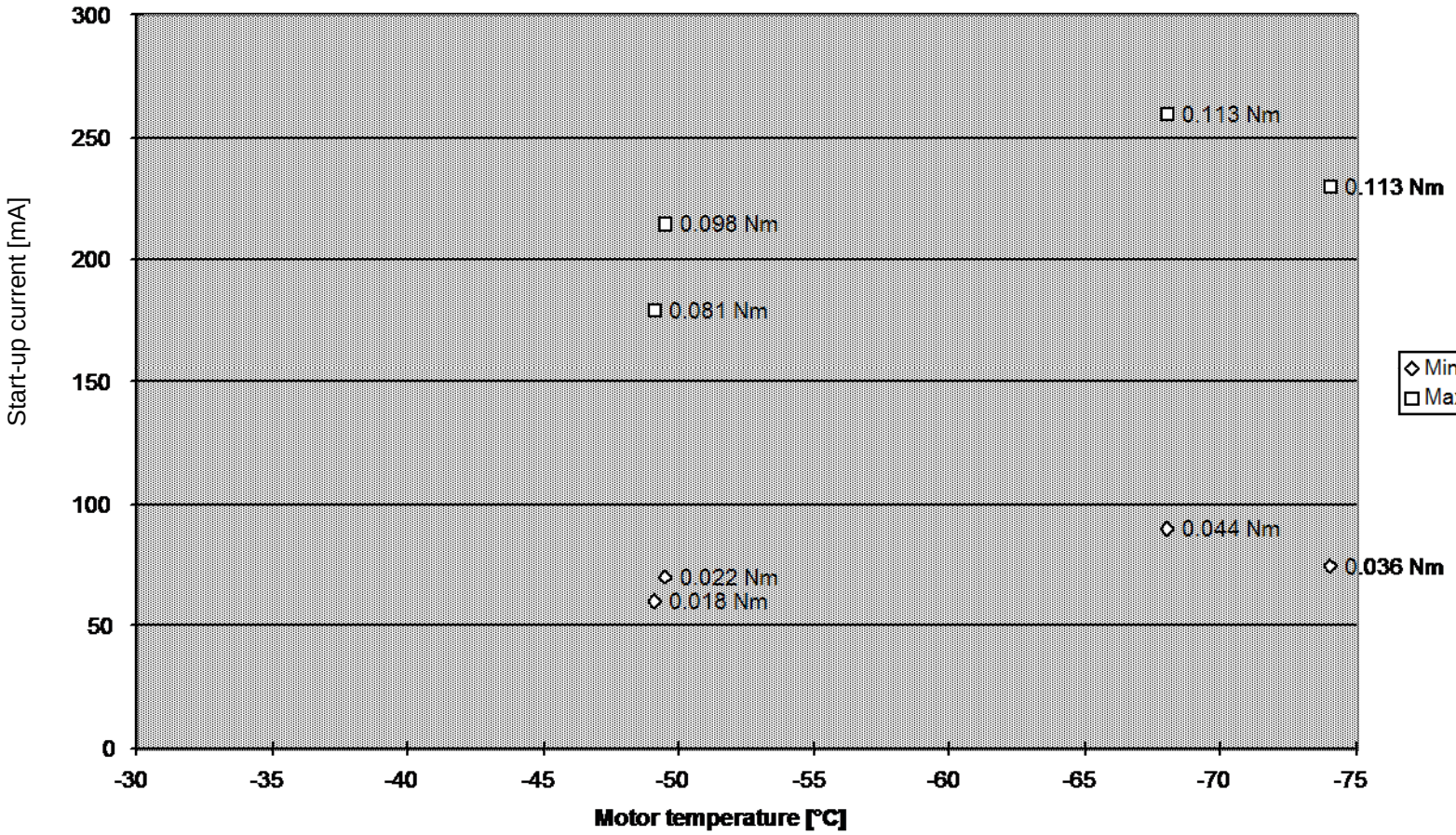
Environmental testing: key to success





Beagle mole actuator tests with applied load (brakes) in Mars simulation chamber

Environmental testing: key to success



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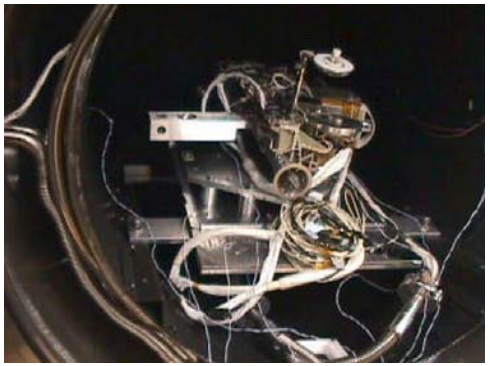
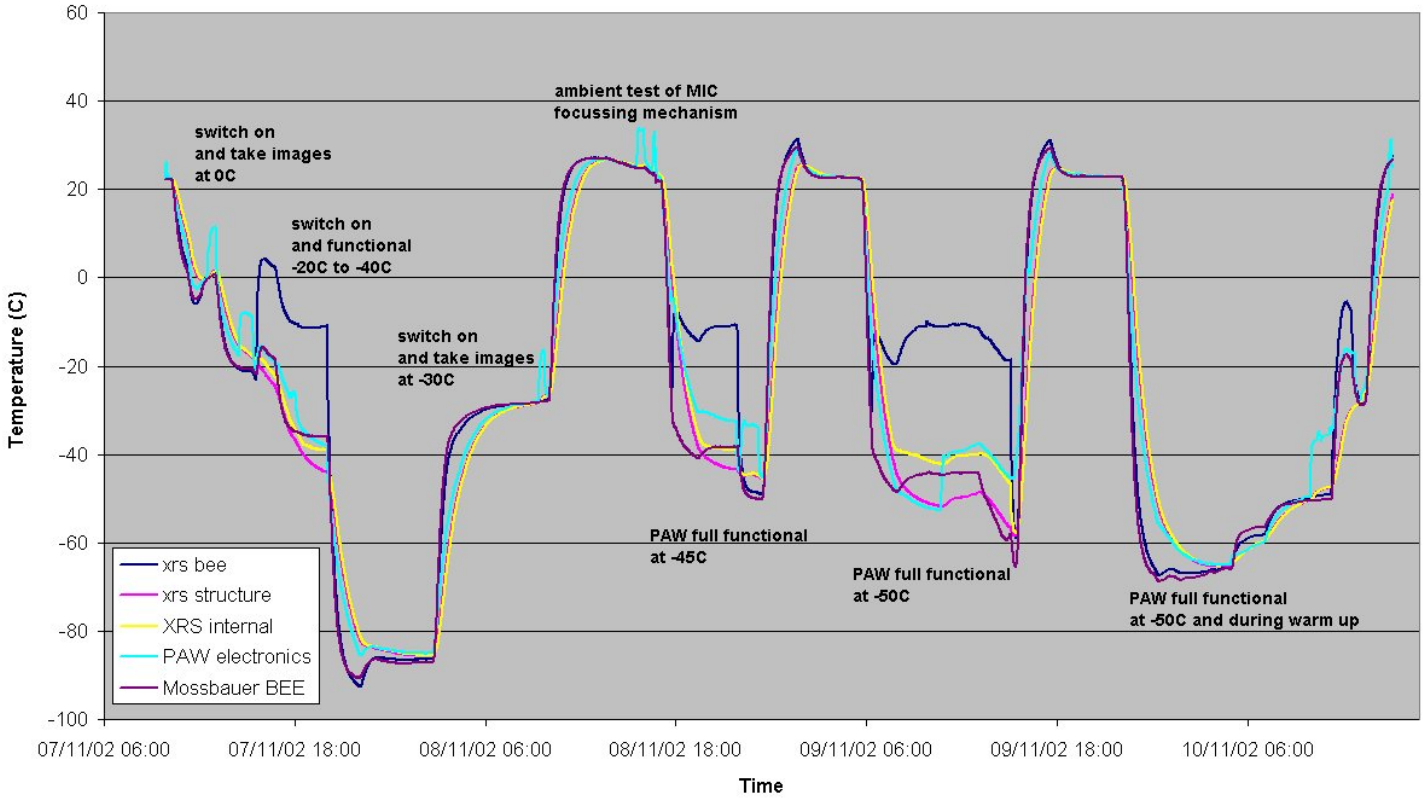


Beagle PAW Flight Model acceptance tests: thermal cycling with functional tests in Mars simulation chamber

Figure 12 - FM PAW/BEE Temperatures



Summary & conclusions

- Large number of successful low temperature mechanisms for planetary surface missions
- Generally feasible:
  - liquid lubrication+local heaters -> but: energy expensive; still: OK for Mars
- For operations below ~ -70 C ambient: solid lubrication preferred
  - But: has issues in atmospheres, requires careful selection of substrate materials & processes
- There are design guidelines for mechanisms: e.g. Space Tribology Handbook (developed and used in Europe) -> use them!

The End